BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W.   WASHINGTON, D.C. 20024

B69 08047

SUBJECT: A Chemical Alternative to the Nuclear Shuttle - Case 730

DATE: August 21, 1969

FROM: E. M. Grenning

NASW-417

ABSTRACT

Within the framework of the Integrated Manned Space Flight Program a spectrum of chemical alternatives to the nuclear shuttle using clustered modified S-IVB's for the first stage and clustered LM/B-Propulsion Modules for the second stage, is presented. The payload performance of the vehicle spectrum as well as a measure of operating costs is given and an example alternative is discussed and compared with the nuclear shuttle. The payload capability of the example vehicle is generally lower, while the number of earth orbital shuttle logistics flights (i.e., operating costs) is about twice that required for nuclear shuttle flights.

(NASA-CR-107463) A CHEMICAL ALTERNATIVE TO THE NUCLEAR SHUTTLE (Bellcomm, Inc.) 17 p

N79-72539

Unclas
00/20 11677

F No. 602A
(PAGES)
CR-107463
(NASA CR OR TMX OR AD NUMBER)
(CATEGORY)
[redacted]

BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B69 08047

SUBJECT: A Chemical Alternative to the Nuclear Shuttle - Case 730

DATE: August 21, 1969

FROM: E. M. Grenning

MEMORANDUM FOR FILE

1.0 INTRODUCTION AND BACKGROUND

In endeavoring to provide a plan for future operations and exploration in space, an integrated manned space flight program covering the years 1970 through 1982, has been synthesized.[1] As shown in Figure 1, the program is characterized by stations in low earth orbit, in lunar orbit, on the lunar surface and in geosynchronous orbit. Transportation to and from these stations is provided by three newly developed vehicles; the earth orbital shuttle, which moves cargo and personnel between the surface of the earth and the low earth orbital station; the LM/B which performs the same function between the lunar surface station and lunar orbital station as well as providing space tug capability when assigned to an orbiting station; and the nuclear shuttle which carries cargo and crew on round trips between the low earth orbital station and lunar orbital and geosynchronous stations. With regard to the nuclear shuttle two important questions have emerged.

1. If safety dictates, can the nuclear shuttle task be performed with other chemical stages in the program?

2. Can such a chemical replacement be cost effective, considering the tradeoff between increased operating costs and reduced development spending?

2.0 NUCLEAR SHUTTLE ALTERNATIVE

Because of the questions above, a study was conducted to see if a chemical replacement for the nuclear shuttle was feasible and attractive.

The primary ground rule in synthesizing an alternative vehicle is that it be composed of other program hardware elements, thereby avoiding an expensive development program. It is desirable that the cost associated with the integration of these elements be small compared to the savings realized by not developing the nuclear shuttle.

Rather than proposing a specific alternative configuration, a spectrum of chemical shuttles varying in size but using the same two hardware elements will be presented. The alternative vehicle consists of two stages; the first composed of a cluster of one to three modified S-IVB's and the second consisting of one to three LM/B - Propulsion Modules (PM's). The modification of the S-IVB consists of replacing the J-2 engine with a reusable engine such as that being considered for the earth orbital shuttle or with a reusable J-2S type of propulsion system. An I_{sp} of 432 seconds (J-2S) is assumed while the dry and propellant weights of the S-IVB are 25,000 lbs and 235,000 lbs respectively.[2,3] The S-IVB is enclosed in a 20 mil aluminum meteoroid shield which protects the tankage and engine plumbing and weighs about 2,500 lbs.[4] A simplified instrument unit and electrical integration system weighing about 1,000 lbs is provided to fulfill the first stage control requirements.[5] The structural interstage between the S-IVB and the PM was assumed to weigh about 1,000 lbs.[5] Therefore, the first stage dry weight is equal to 4,500 lbs plus the dry weight of the S-IVB's.

The LM/B-PM I_{sp} is 460 seconds with dry and propellant weights of 10,000 lbs and 40,000 lbs, respectively.[1] The second stage dry weight is assumed to be the summation of the LM/B-PM weights. This is justified on the basis of the relatively low LM/B-PM mass fraction of $\lambda = .8$.

A sketch of the alternative vehicle is presented in Figure 2 and a first stage weight summary is given in Table 1. The first stage integration subsystem weights are approximate, but conservative.

3.0 SHUTTLE MISSION PROFILE

The S-IVB mission profile which remains the same for every flight is presented in Figure 3. A general LM/B profile is presented in Figure 4. The geosynchronous logistics mission profile is similar to the lunar logistics profile described below except for the different velocity increments required.

The first stage accelerates the second stage and lunar orbit payload, including the crew capsule, through translunar injection (TLI). During a 5 minute coast period, the S-IVB attitude is changed by approximately 180° and stabilized using the guidance and navigation system in the crew capsule in conjunction with the first stage auxiliary propulsion system.

After separation, the S-IVB is burned to depletion thus placing it in elliptical earth orbit, about 520 by 250 n.mi., whose energy is quite close to that of the 250 n.mi. altitude circular departure orbit. The space tug assigned to the low altitude earth orbital station then retrieves the empty stage in preparation for the next shuttle trip.

The second stage and payload continue to the moon, performing whatever midcourse corrections and plane change maneuvers are needed. Lunar orbit insertion (LOI) of the payload is performed by the second stage. After the payload is transferred to the lunar orbital space station the stage returns itself, and some return payload if any is required, to earth orbit via transearth (TEI) and earth orbit injection (EOI) maneuvers. The up payload must be sized to leave enough propellant after LOI for the return flight. Upon arrival at earth orbit the space tug retrieves the empty stage for rejoining with the first stage in preparation for the next trip.

Table 2 presents the estimated velocity changes for all of the maneuvers performed by the first and second stages. The TLI, LOI and TEI velocity increments are taken from the Apollo ΔV budget.[6] The retrograde TLI velocity change is assumed to be the same as TLI but applied in an approximately opposite sense. The EOI velocity increment is assumed to be the same magnitude as the TLI velocity change. Also given in Table 2 are the estimated velocity increments for the geosynchronous orbital logistics mission.[7,8] The estimated magnitudes of all velocity increments are approximate but conservative.

Note that there are three distinct payloads to be considered in the analysis.

1. The payload to be carried to lunar orbit.

2. The payload carried out of lunar orbit but not retroed into earth orbit, such as an Apollo CM.

3. The payload carried out of lunar orbit and delivered to earth orbit, such as a space crew capsule.

4.0 PERFORMANCE

Figures 5, 6 and 7 give lunar orbit payloads (P/L LOI) as a function of transearth payload (P/L TEI) for parametric values of earth orbit insertion payload (P/L EOI), for a second stage consisting of one, two and three, LM/B-PM's, respectively. Also shown in each Figure is the loci of equal TEI and EOI payload as well as the special case of constant round trip payload. For the purpose of comparison with the nuclear shuttle the total number of earth orbital shuttle flights required for propellant and cargo transportation to earth orbit per alternative shuttle flight is also presented in each figure. Earth orbital shuttle supply flights per alternative shuttle mission is considered to be a crude measure of the operations expense incurred for each alternative shuttle flight.*

Perhaps the most efficient manner of illustrating the use of the figures is to provide some examples. Assume that we wish to return from the moon using a Gemini-B capsule, at 20,000 lbs, for aerodynamic braking into earth orbit. The EOI payload is thus 0, while the TEI payload is 20K. The lunar orbit payloads for 1, 2, and 3 S-IVB/LM-B combinations are 50K, 120K, and 190K respectively. They will require, respectively 8, 16, and 23 space shuttle flights to bring up fuel and payload.

Consider a shuttle consisting of a cluster of two S-IVB's and two LM/B-PM's the payload performance of which is given in Figure 6. The round trip payload is 18,700 lbs while for zero return payload the LOI payload is 145,000 lbs. The two intermediate LOI payloads of 90,000 lbs and 73,000 lbs correspond to return payloads of 8,000 lbs and 11,000 lbs, respectively. The round trip flight requires about 14 earth orbital shuttle supply flights while the two intermediate LOI payload missions require 15 each. The zero return payload trip requires 16 earth orbital shuttle missions. Table 3 presents a comparison of the chemical and nuclear shuttles for both lunar and geosynchronous logistics missions.

---

*Because of the short coast time capability of the S-IVB, fueling must be accomplished in a relatively short time. This suggests salvo launching of the fueling shuttles, or use of an orbital tanking facility. Modifying the S-IVB for longer coast capability would also solve the problem.

As a further example in using the figures, consider the same shuttle delivering 100,000 lbs to the lunar orbital station, accelerating a crew return reentry module through TEI and deboosting only the LM/B's through EOI. According to Figure 6 for a zero EOI payload the reentry module could weigh no more than 40,000 lbs. If it were desired to deboost 5,000 lbs of payload through EOI in addition to accelerating a reentry module through TEI then the module could weigh no more than 15,000 lbs. The required earth orbital shuttle logistics flights are obtained from Figure 6 in the same manner as in the previous example.

5.0 SHUTTLE COST

From the example it is apparent that the expense of operating the chemical shuttle is about double that of the nuclear shuttle. Not shown in Table 3 are the launch operations required to place the shuttles in earth orbit ready for logistics operations. The nuclear shuttle would require one INT-21 launch (payload ~250,000 lbs) and a single ground-to-orbit shuttle (space shuttle) flight (payload ~50,000 lbs) to fill the off loaded hydrogen tank for the first flight. The nuclear shuttle would be delivered to low earth orbit in its completed configuration thus precluding the need for orbital construction operations. The example chemical shuttle would require two INT-21 launches and up to three earth orbital shuttle flights as well as orbital assembly and docking operations to build the shuttle in space. The cost of initiating logistics operations for the example shuttle would therefore be higher than for the nuclear shuttle. A detailed cost comparison of the shuttles is beyond the scope of this memorandum, but in general it appears that the alternative shuttle would be less costly to develop but considerably more expensive to initiate and operate. However the basic feasibility of lunar shuttle operations using modifications of chemical vehicles in the basic program is clear.

1012-EMG-kle

E. M. Grenning

E. M. Grenning

REFERENCES

1. "An Integrated Program of Space Utilization and Exploration for the Decade 1970 to 1980", NASA, Washington, D. C.

2. Private conversation with A. E. Marks.

3. "Press Kit - Apollo 11 Lunar Landing Mission", NASA, July 6, 1969, Washington, D. C.

4. Private conservation with C. E. Johnson.

5. Skeer, M. H., "Preliminary Design of a Cryogenic Planetary Propulsion Module", Bellcomm TM 67-1013-2, May 10, 1967.

6. "Apollo Lunar Landing Mission Symposium - Volume I, NASA/MSC, June 25-27, 1966."

7. TRW/STL "Space Data Book".

8. Bosch, H. B., "Characteristic Velocity Requirements for Intraorbital Transfer Missions," Bellcomm Memorandum for File, July 14, 1969.

TABLE 1 FIRST STAGE WEIGHT SUMMARY

NO OF S-IVB'S	1	2	3
Meteoroid Shielding	2,500 lbs		
Instrument Units & Electrical Integration System	1,000 lbs		
Structural Integration System	1,000 lbs		
Dry Weight of S-IVB'S	25,000 lbs	50,000	75,000
Total Propellant Weight	235,000 lbs	470,000	705,000
First Stage Gross Weight	264,500 lbs	524,500	784,500

TABLE 2 SHUTTLE VELOCITY CHANGES

LUNAR LOGISTICS

	MANEUVER	ΔV (FPS)
1.	Translunar Injection (TLI	$\sim$10,000
2.	Retrograde TLI (RTLI)	$\sim$10,000
3.	Lunar Orbit Insertion (LOI)	$\sim$ 3,500
4.	Transearth Injection (TEI)	$\sim$ 3,100
5.	Earth Orbit Insertion (EOI)	$\sim$10,000

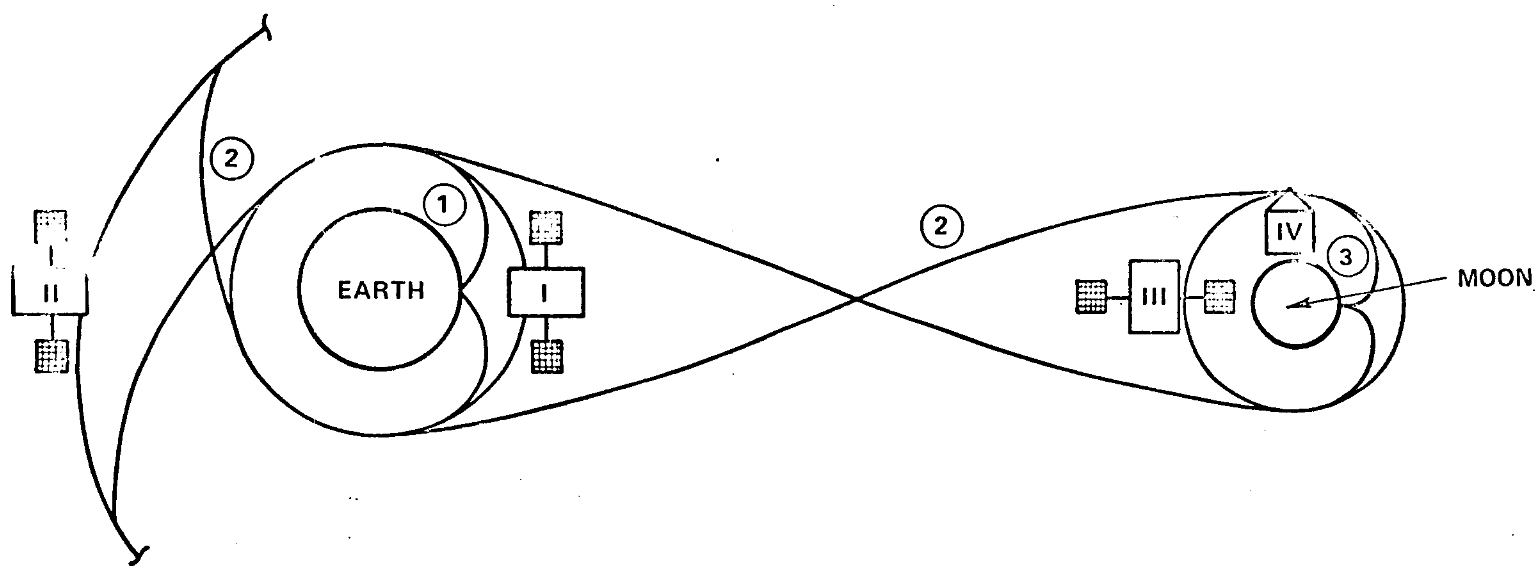
GEOSYNCHRONOUS LOGISTICS

	MANEUVER	ΔV (FPS)
1.	Transgeosynchronous Injection (TGI)	$\sim$ 8,000
2.	Retrograde TGI (RTGI)	$\sim$ 8,000
3.	Geosynchronous Orbital Insertion (GOI)	$\sim$ 6,000
4.	Geosynchronous Transearth Injection (GTEI)	$\sim$ 6,000
5.	Geosynchronous Earth Orbit Insertion (GEOI)	$\sim$ 8,000

TABLE 3 COMPARISON OF ALTERNATIVE AND NUCLEAR SHUTTLE

NUCLEAR SHUTTLE			CHEMICAL SHUTTLE (2 PARALLEL STAGES)		
LOI PAYLOAD (LBS)	RETURN PAYLOAD (LBS)	EARTH ORBITAL SHUTTLE FLIGHTS	LOI PAYLOAD (LBS)	RETURN PAYLOAD (LBS)	EARTH ORBITAL SHUTTLE FLIGHTS
44,000	44,000	6	18,700	18,700	14
120,000	0	7	145,000	0	16
90,000	17,000	7	90,000	8,000	15
73,000	27,000	6	73,000	11,000	15
GEOSYNCHRONOUS PAYLOAD (LBS)	RETURN PAYLOAD	EARTH ORBITAL SHUTTLE FLIGHTS	GEOSYNCHRONOUS PAYLOAD (LBS)	RETURN PAYLOAD (LBS)	EARTH ORBITAL SHUTTLE FLIGHTS
38,000	42,000	6	8,000	8,000	12
84,000	17,000	7	22,000	5,000	12

FIGURE 1 - INTEGRATED MANNED SPACE FLIGHT PROGRAM



STATIONS		TRANSPORTATION VEHICLES	
EARTH ORBIT			
I	LOW ALTITUDE,	1.	EARTH ORBITAL SHUTTLE
II	SYNCHRONOUS,	2.	NUCLEAR SHUTTLE
		3.	LM-B (SPACE TUG)
LUNAR			
III	ORBIT,		
IV	SURFACE,		

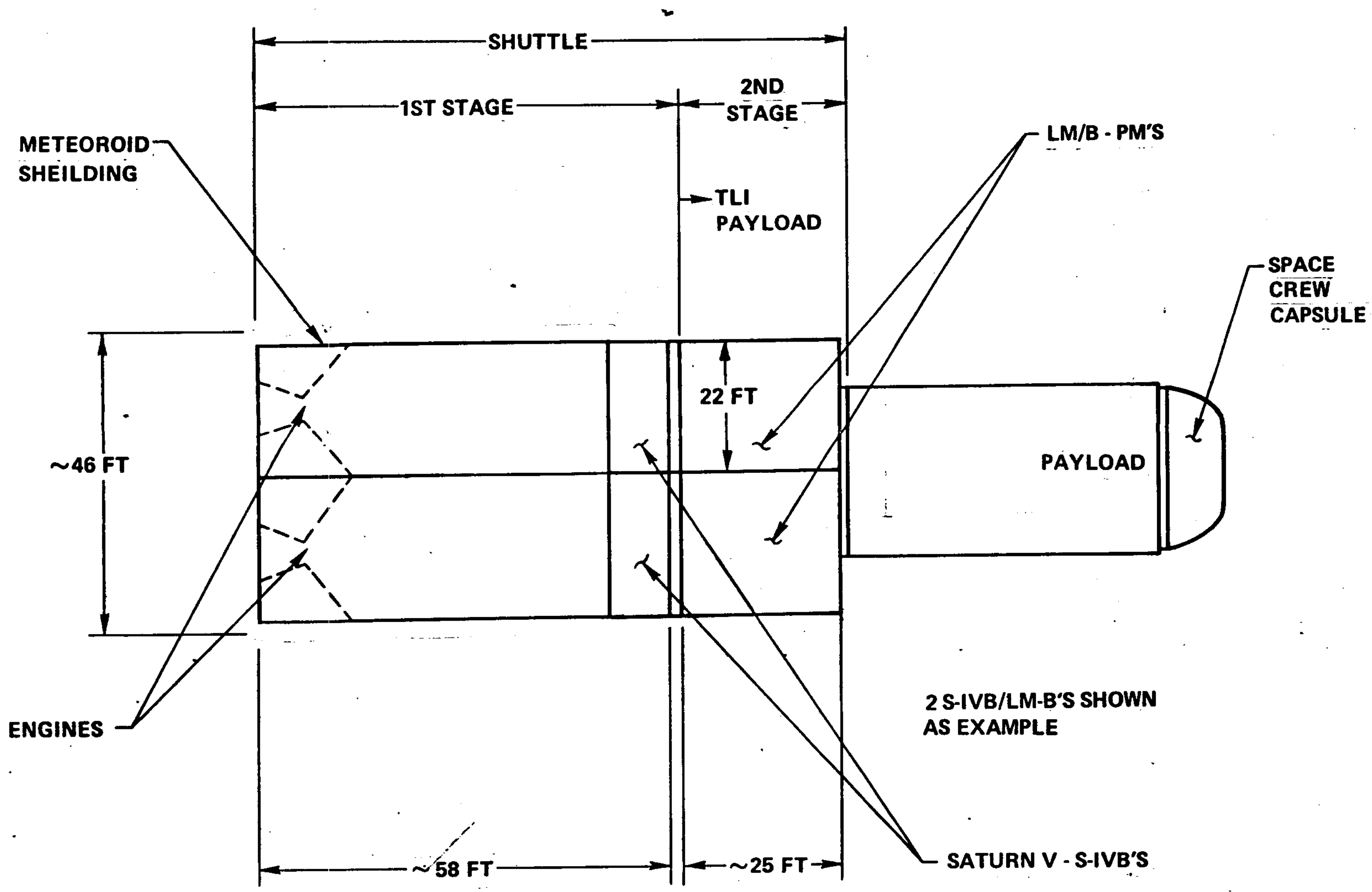


FIGURE 2 - ALTERNATIVE CHEMICAL SHUTTLE

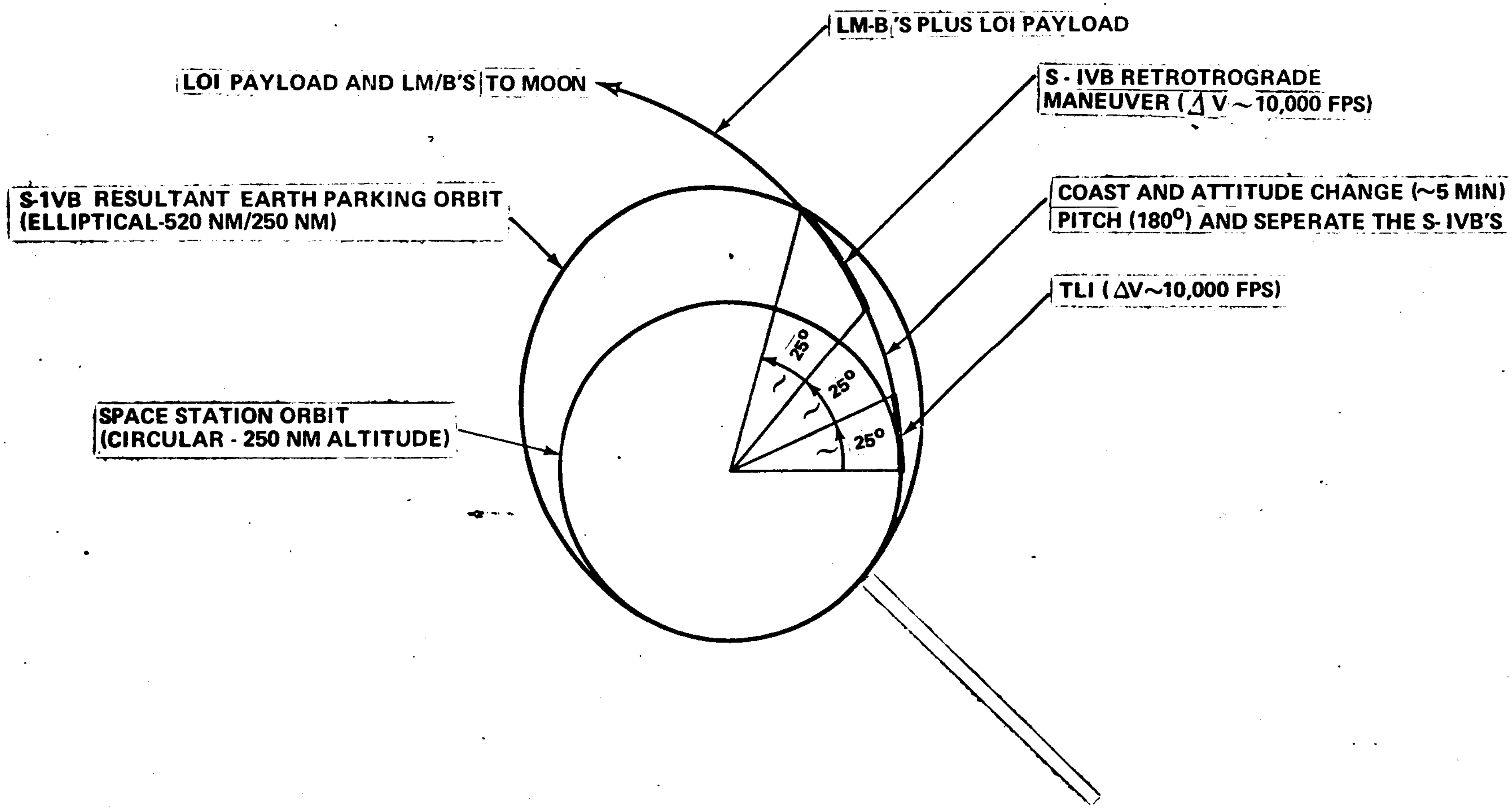


FIGURE 3- S- IVB MISSION PROFILE

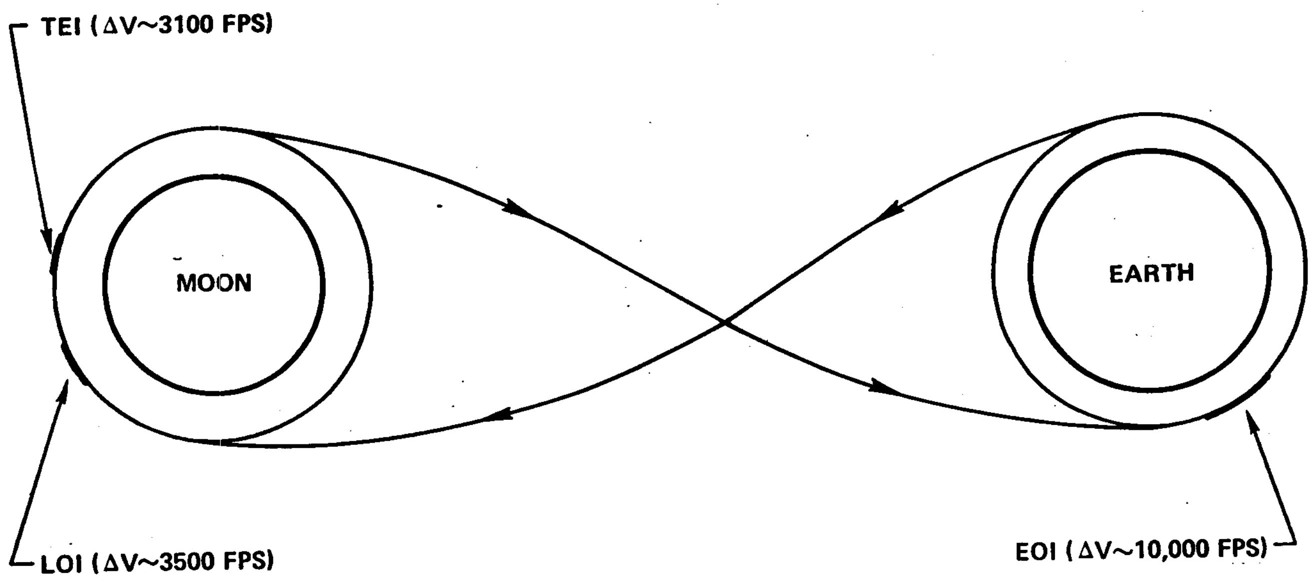


FIGURE 4- LM-B MISSION PROFILE

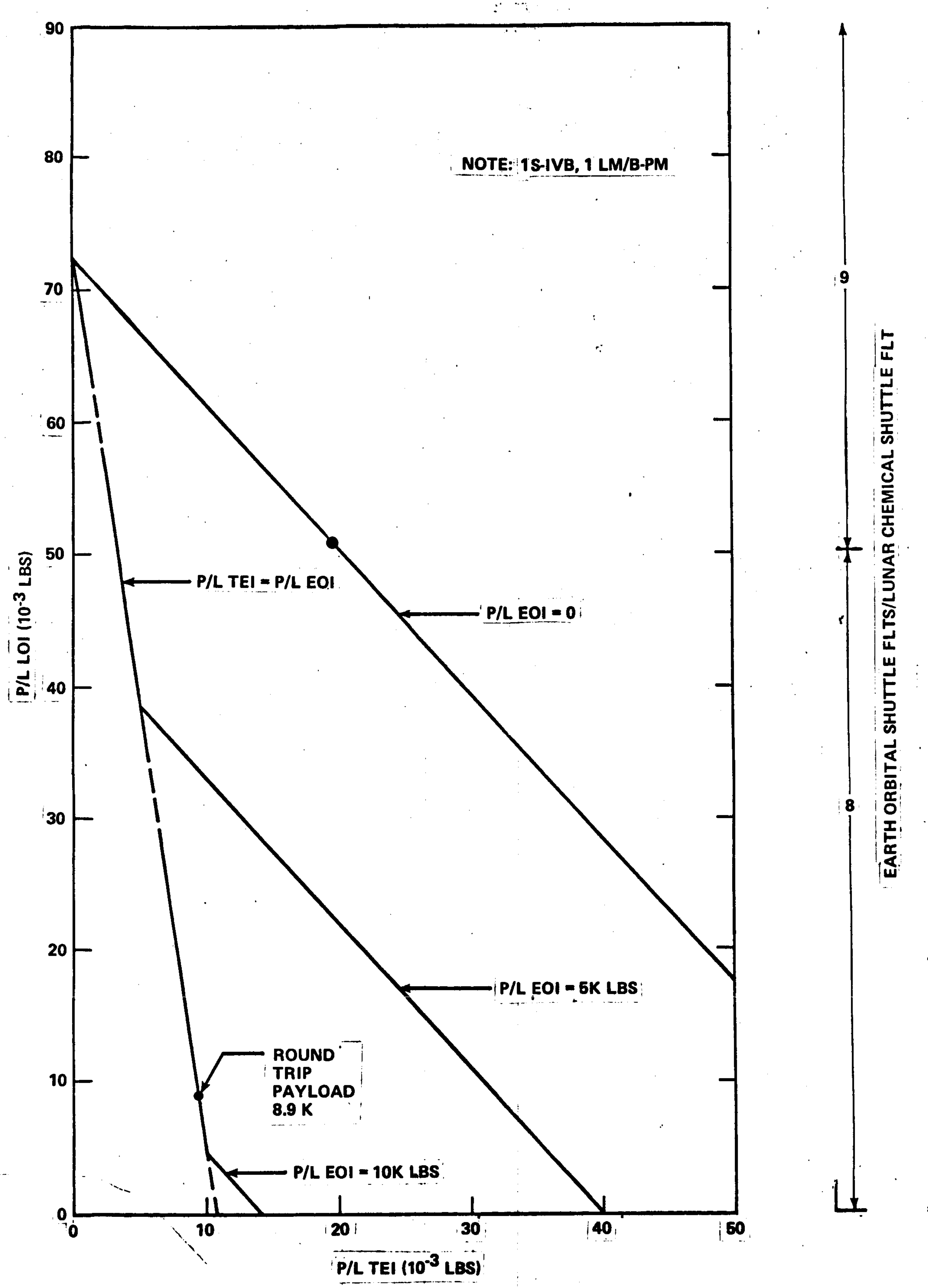


FIGURE 5 - CHEMICAL SHUTTLE 2ND STAGE - 1 LMB/PM

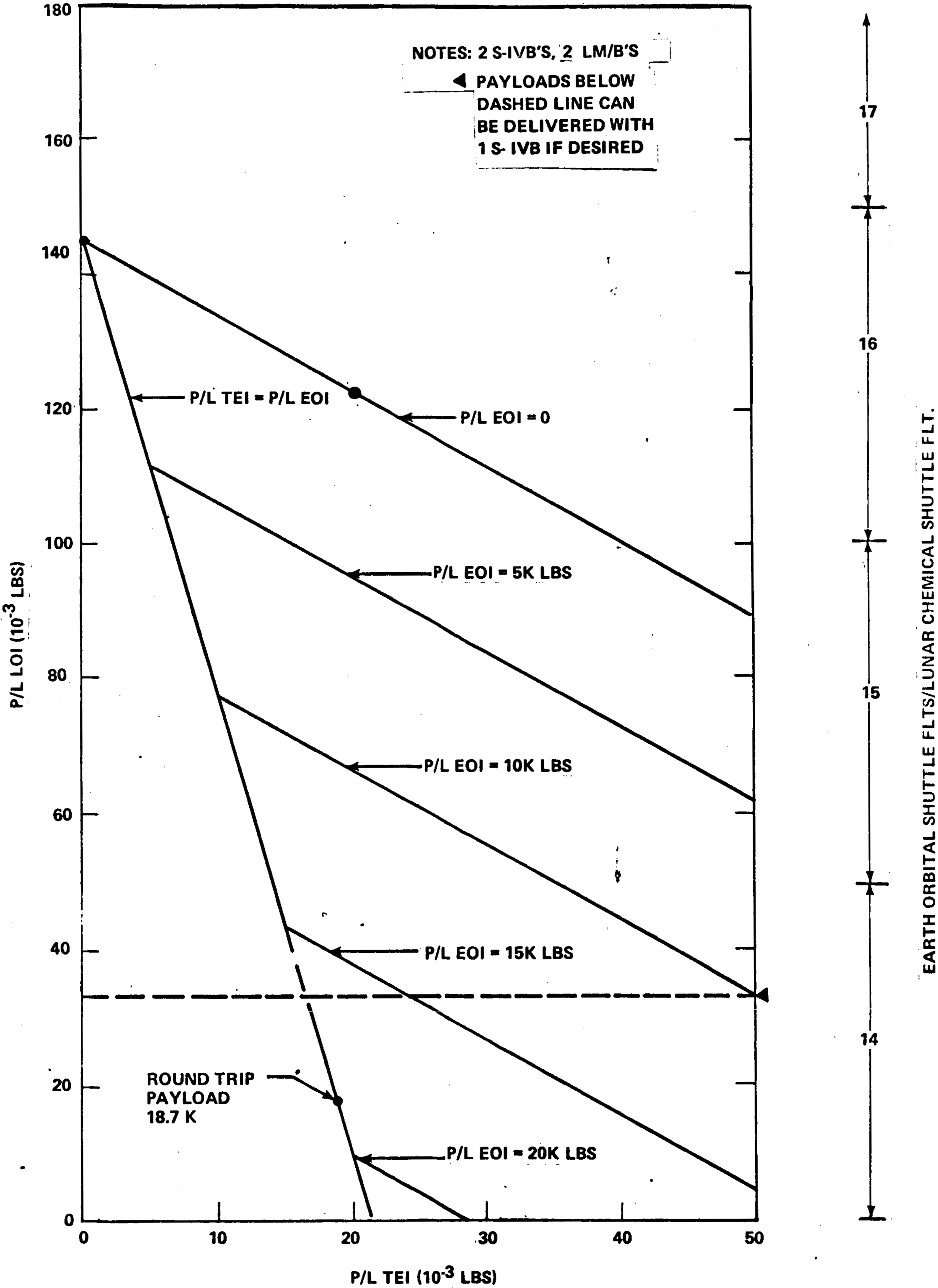


FIGURE 6 - CHEMICAL SHUTTLE 2ND STAGE - 2 LMB/PM'S

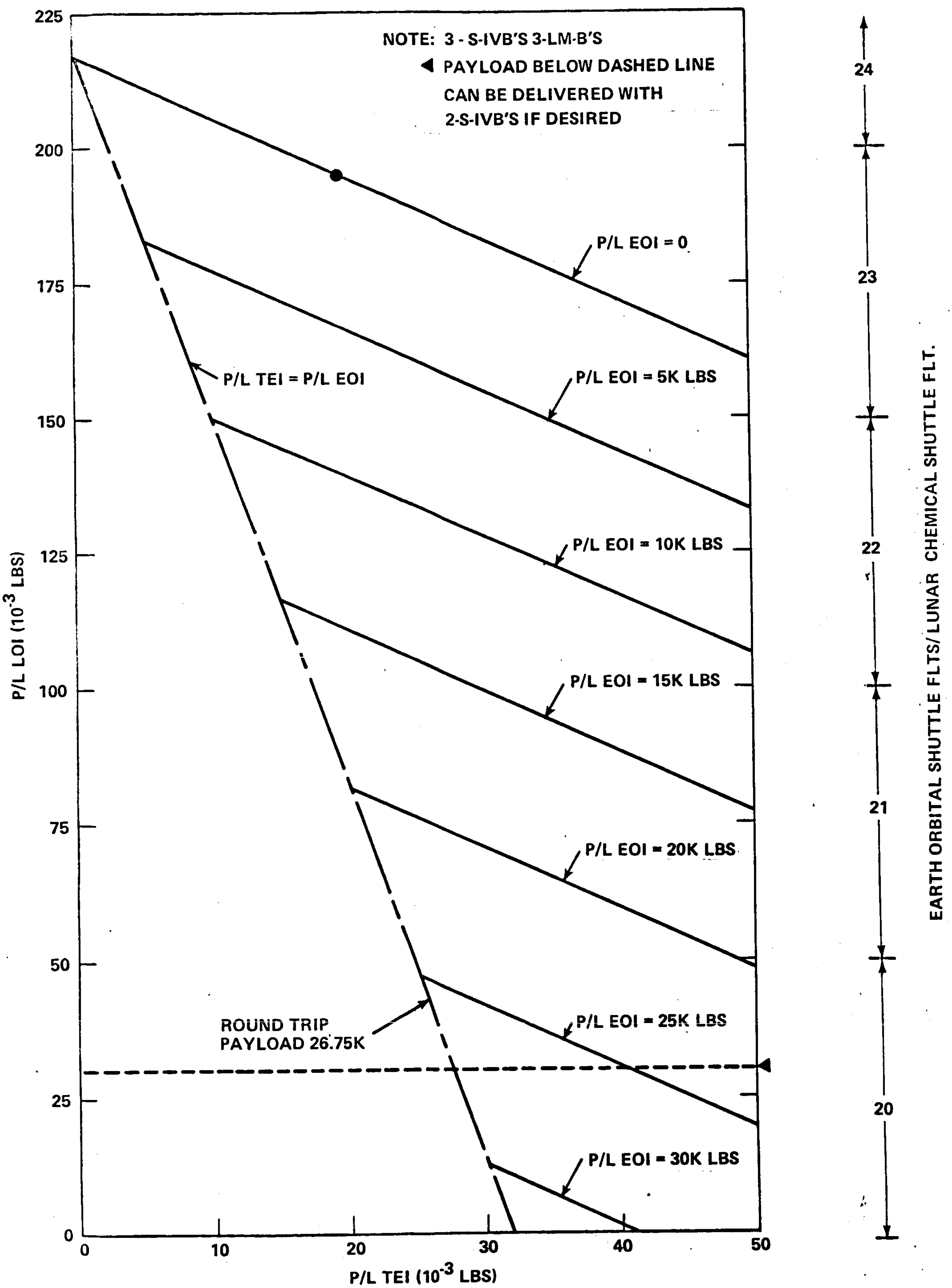


FIGURE 7 - CHEMICAL SHUTTLE 2ND STAGE - 3 LMB/PM'S